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DECLARATION

I, NOBUAKI KATO, a Japanese Patent Attorney registered No.08517, of Okabe International Patent Office at No. 602, Fuji Bldg., 2-3, Marunouchi 3-chome, Chiyoda-ku, Tokyo, Japan, hereby declare that I have a thorough knowledge of Japanese and English languages, and that the attached pages contain a correct translation into English of the priority documents of Japanese Patent Application No. 2000-265821 filed on September 1, 2000 in the name of CANON KABUSHIKI KAISHA.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made, are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed this 6-th day of February, 2004

NOBUAKI KATO

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Applicant(s): CANON KABUSHIKI KAISHA

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[Title of the Invention] ELECTRON-EMITTING DEVICES, ELECTRON SOURCES, AND IMAGE-FORMING APPARATUS

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[Inventor]

[Domicile or Residence] c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko, Ohta-ku, Tokyo

[Name] SHINICHI KAWATE

[Inventor]

[Domicile or Residence] c/o Canon Kabushiki Kaisha
30-2, 3-chome, Shimomaruko, Ohta-ku, Tokyo

[Name] TAKEO TSUKAMOTO

[Applicant]

[Identification No.] 000001007

[Name] CANON KABUSHIKI KAISHA

[Representative] FUJIO MITARAI

[Attorney]

[Identification No.] 100085006

[Patent Attorney]

[Name] KAZUNOBU SERA

[Telephone No.] 03-5643-1611

[Elected Attorney]

[Identification No.] 100100549

[Patent Attorney]

[Name] YOSHIYUKI KAWAGUCHI

[Elected Attorney]

[Identification No.] 100106622

[Patent Attorney]

[Name] JUNICHI WAKUTA

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[Mateiral]	Drawing	1
[Material]	Abstract	1
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[Name of the Document] Specification

[Title of the Invention] Electron-emitting Devices, Electron Sources, and Image-forming Apparatus

[Claim(s)]

[Claim 1] An electron-emitting device comprising:

an extraction electrode and a negative electrode formed in opposition to each other with a gap between said extraction electrode and said negative electrode on an electrically insulating substrate;

a conductive layer formed on said negative electrode;

a catalyst particle disposed on a side wall surface of said conductive layer on the extraction electrode side; and

a fibrous carbon grown through said catalyst particle.

[Claim 2] The electron-emitting device according to Claim 1, wherein the conductive layer formed on said negative electrode consists of a material on which said fibrous carbon grows through said catalyst particle.

[Claim 3] The electron-emitting device according to Claim 2, wherein said material, on which the fibrous carbon grows, is a mixture of Ti and an oxide thereof resulting from partial oxidation of Ti, or an oxide semiconductor of Ti; or a mixture of Zr and an oxide

thereof resulting from partial oxidation of Zr, or an oxide semiconductor of Zr; or a mixture of Nb and an oxide thereof resulting from partial oxidation of Nb, or an oxide semiconductor of Nb.

[Claim 4] The electron-emitting device according to Claim 2 or 3, wherein only the side wall surface of the extraction electrode side for said conductive layer formed on said negative electrode is exposed and the other surfaces thereof are covered with a material on which said fibrous carbon does not grow.

[Claim 5] The electron-emitting device according to Claim 4, wherein said material, on which the fibrous carbon does not grow, contains a second conductive layer for covering a upper surface of said conductive layer and a side wall surface other than the side wall surface of said extraction electrode side.

[Claim 6] The electron-emitting device according to Claim 5, wherein said second conductive layer is at least either one of Ta, Cr, Au, Ag, Pt, and materials of the same kind as a material making said catalyst particle.

[Claim 7] The electron-emitting device according to any one of Claims 1 to 6, wherein said fibrous carbon consists of a graphite nanofiber, a carbon nanotube, or an amorphous carbon, grown by decomposing a hydrocarbon gas under use of a catalyst, or a mixture thereof.

[Claim 8] The electron-emitting device according to any one of Claims 1 to 7, wherein said catalyst particle consists of Pd, Ni, Fe, Co, or an alloy thereof.

[Claim 9] The electron-emitting device according to any one of Claims 1 to 8, wherein an electron emission position from said fibrous carbon is at the electron emitting direction side against a position of a surface of said extraction electrode.

[Claim 10] The electron-emitting device according to any one of Claims 1 to 9, wherein said extraction electrode and negative electrode are formed on substantially planar shape of a substrate and a thickness of said negative electrode is larger than a thickness of the extraction electrode.

[Claim 11] The electron-emitting device according to any one of Claims 1 to 9, wherein said substrate is thicker in a region where said negative electrode is formed than in a region where said extraction electrode is formed.

[Claim 12] The electron-emitting device according to any one of Claims 1 to 9, wherein said conductive layer is formed on a region spreading from on said negative electrode to inside of the gap between said extraction electrode and negative electrode on a surface of the substrate.

[Claim 13] An electron source wherein a plurality

of electron-emitting devices as set forth in any one of Claims 1 to 12 are arrayed.

[Claim 14] The electron source according to Claim 13, wherein said plurality of electron-emitting devices are electrically connected to a matrix wiring pattern.

[Claim 15] An image-forming apparatus wherein an image-forming member for forming an image by collision of emitted electrons is disposed at a position where the image-forming member faces the electron source as set forth in Claim 13 or 14; and

a control mechanism for controlling electron-emitting devices for emitting electrons is equipped with.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to electron-emitting devices for emission of electrons, electron sources using them, and image-forming apparatus using the electron sources. The image-forming apparatus according to the present invention can be used in display devices for television broadcasting, display devices of video conference systems, computers, etc., optical printers constructed with use of a photosensitive drum or the like, and so on.

[0002]

[Prior Art]

Conventionally, field emission type (FE type) electron-emitting devices configured to apply a strong electric field of not less than 10^6 V/cm to metal and thereby emit electrons from the metal surface are drawing attention as one of cold electron sources.

[0003]

Recently, especially concerning the image forming apparatus like a display device, a flat-panel type display device using liquid crystal (LC) has been disseminated in place of CRT. But the LC display has problems such that backlight is required as it is not an emissive type, and therefore an emissive type display device is demanded.

[0004]

If such FE type cold electron sources become practically available, it will become feasible to construct low-profile emissive type image display devices and they will also contribute to reduction in power consumption and reduction in weight.

[0005]

Known as an example of a vertical FE type is a device in which, as shown in Fig. 13, an emitter 135 is of the shape of a circular cone or a quadrangular pyramid formed from a substrate 131 approximately in the vertical direction; for example, one disclosed in C. A. Spindt, "Physical Properties of thin-film field emission cathodes with molybdenum cones," J. Appl.

Phys., 47, 5248 (1976) or the like (hereinafter referred to as a Spindt type).

[0006]

As an example of a lateral FE structure, an emitter electrode sharp-pointed at the tip and a gate electrode for extracting electrons from the emitter tip are arranged in parallel with a substrate and the collector (called "anode" in this case) is disposed in the direction orthogonal to the direction where the gate electrode and the emitter electrode are in opposition to each other.

[0007]

As an example of the electron-emitting devices using fibrous carbon, Japanese Patent Application Laid-Open No. 8-115652 discloses a configuration in which thermal decomposition is implemented in the presence of organic compound gas on fine particles of catalyst metal whereby fibrous carbon is deposited in a fine gap.

[0008]

The beam profiles of the electron-emitting devices according to the prior arts will be described referring to Figs. 13 and 14.

[0009]

In Fig. 13, which shows the Spindt type electron-emitting device according to the foregoing prior art, numeral 131 denotes the substrate, 132 the emitter electrode, 133 the insulating layer, 134 the gate, and

135 the emitter connected to the emitter electrode 132. When Vf is placed between the emitter 135 and the gate 134, the electric field becomes stronger at the tip of the projection of the emitter 135 and then electrons are emitted from the vicinity of the tip of the cone into the vacuum.

[0010]

Since the electric field at the tip of the emitter is formed in such a certain finite area as to follow the shape of the emitter tip, the extracted electrons are drawn in the vertical direction relative to the potential from the finite area at the emitter tip.

[0011]

At this time, electrons are also emitted at various angles. As a result, electrons with large angle components are drawn in directions toward the internal peripheral surface in the hole formed in the gate 134.

[0012]

As a consequence, where the hole is circular, an electron distribution obtained on the anode 136 in the figure becomes a substantially circular beam profile 137. This indicates that the resultant beam profile is in close relation with the shape of the gate and the distance to the emitter.

[0013]

The lateral FE configuration as shown in Fig. 14

is the prior art in which electrons are emitted in the aligned extraction direction.

[0014]

In Fig. 14, numeral 141 designates the substrate, 142 the emitter electrode, 143 the insulating layer, 144 the gate, and 145 the emitter, and the anode 146 is provided on a substrate opposed to the substrate on which the emitter and gate are disposed.

[0015]

In the case of the lateral FE configuration constructed in this way, some of electrons emitted from the emitter 145 are extracted (or emitted) into the vacuum, but the rest are taken into the gate 144.

[0016]

In the configuration shown in Fig. 14, the direction of the electric field vector for emission of electrons (the electric field from the emitter 145 toward the gate 144) is different from the direction of the electric field vector toward the anode 146. As a result, the electron distribution (electron beam spot) becomes large. Because of this, as means for converging beams in the lateral FE type electron-emitting devices, as being disclosed in Japanese Patent Application Laid-Open No. 09-063461, the configurations such that a convergent electrode is arranged on the same plane with the electron-emitting portion are proposed, but these configurations have problems such

as too complicated production method, increased device area and deteriorated electron-emitting efficiency.

[0017]

[Problem to be Solved by the Invention]

The present invention has been accomplished in order to solve the above problems in prior art and an object of the invention is to provide electron-emitting devices that are reduced in the device capacitance and the driving voltage and improved in the electron emission efficiency and that can provide a high-definition beam, and electron sources and image-forming apparatus using them.

[0018]

[Means for solving the Problem]

In order to achieve the above object, an electron-emitting device comprises an extraction electrode and a negative electrode formed in opposition to each other with a gap between the extraction electrode and the negative electrode on an electrically insulating substrate, a conductive layer formed on the negative electrode, a catalyst particle disposed on a side wall surface of the conductive layer on the extraction electrode side, and a fibrous carbon grown through the catalyst particle.

[0019]

It is favorable that the conductive layer formed on the negative electrode consists of a material on

which the fibrous carbon grows through the catalyst particle.

[0020]

It is favorable that the material, on which the fibrous carbon grows, is a mixture of Ti and an oxide thereof resulting from partial oxidation of Ti, or an oxide semiconductor of Ti; or a mixture of Zr and an oxide thereof resulting from partial oxidation of Zr, or an oxide semiconductor of Zr; or a mixture of Nb and an oxide thereof resulting from partial oxidation of Nb, or an oxide semiconductor of Nb.

[0021]

It is favorable that only the side wall surface of the extraction electrode side for the conductive layer formed on the negative electrode is exposed and the other surfaces thereof are covered with a material on which the fibrous carbon does not grow.

[0022]

It is favorable that the material, on which the fibrous carbon does not grow, contains a second conductive layer for covering a upper surface of the conductive layer and a side wall surface other than the side wall surface of the extraction electrode side.

[0023]

It is favorable that the second conductive layer is at least either one of Ta, Cr, Au, Ag, Pt, and materials of the same kind as a material making the

catalyst particle.

[0024]

It is favorable that the fibrous carbon consists of a graphite nanofiber, a carbon nanotube, or an amorphous carbon, grown by decomposing a hydrocarbon gas under use of a catalyst, or a mixture thereof.

[0025]

It is favorable that the catalyst particle consists of Pd, Ni, Fe, Co, or an alloy thereof.

[0026]

It is favorable that an electron emission position from the fibrous carbon is at the electron emitting direction side against a position of a surface of the extraction electrode.

[0027]

It is favorable that the extraction electrode and negative electrode are formed on substantially planar shape of a substrate and a thickness of the negative electrode is larger than a thickness of the extraction electrode.

[0028]

It is favorable that the substrate is thicker in a region where the negative electrode is formed than in a region where the extraction electrode is formed.

[0029]

It is favorable that the conductive layer is formed on a region spreading from on the negative

electrode to inside of the gap between the extraction electrode and negative electrode on a surface of the substrate.

[0030]

In an electron source according to the present invention, a plurality of electron-emitting devices as set forth in above are arrayed.

[0031]

It is favorable that the plurality of electron-emitting devices are electrically connected to a matrix wiring pattern.

[0032]

In an image-forming apparatus according to the present invention, an image-forming member for forming an image by collision of emitted electrons is disposed at a position where the image-forming member faces the electron source as set forth in above, and a control mechanism for controlling electron-emitting devices for emitting electrons is equipped with.

[0033]

[Embodiment(s)]

The embodiments of the present invention will be illustratively described hereinafter in detail with reference to the drawings. It is, however, noted that, as to the dimensions, materials, shapes, relative locations, etc. of the components described in the embodiments, the scope of the invention is by no means

intended to be limited only to those unless otherwise stated specifically.

[0034]

The growth of the fibrous carbon is explained by a contact angle between a catalyst material and a substrate, or surface energy as shown in J. Mater. Res., Vol. 8, No. 12, P3233.

[0035]

The inventors were dedicated to conducting research on materials that permitted fine (several nm order) nuclei (catalyst particles) to be formed thereon from a catalyst and that formed stable electrical coupling with fibrous carbons grown from the nuclei by thermal decomposition. The "fibrous carbons" can also be said as "columnar substances comprising carbon as a main component" or "linear substances comprising carbon as a main component". The "fibrous carbons" can also be mentioned as "fibers comprising carbon as a main component". More specifically, the "fibrous carbons" in the present invention embrace carbon nanotubes, graphite nanofibers, and amorphous carbon fibers.

[0036]

From the research, the inventor found that materials permitting the growth of the fibrous carbons and achieving electrical coupling therewith include a mixture of Ti and an oxide thereof resulting from partial oxidation of Ti, or an oxide semiconductor of

Ti; or a mixture of Zr and an oxide thereof resulting from partial oxidation of Zr, or an oxide semiconductor of Zr; or a mixture of Nb and an oxide thereof resulting from partial oxidation of Nb, or an oxide semiconductor of Nb.

[0037]

In tandem with it, the inventor also found that materials on which no fibrous carbon grew were Ta, Cr, Au, Ag, Pt, and materials of the same kinds as the catalyst materials.

[0038]

The growth of the fibrous carbons over these materials is also valid in the layered structure. For example, Cr was deposited over the entire surface of a substrate, a fine region of titanium oxide was further formed on the Cr layer, and the entire surface of the substrate was coated with palladium oxide. With use of this substrate, the fibrous carbons were selectively grown only above Ti.

[0039]

Next, a case where a phosphor is used on the positive electrode will be explained. The necessary vertical field is limited to the range of not less than 10^{-1} V/μm nor more than 10 V/μm. For example, when 10 kV is applied in the gap of 2 mm between the positive electrode and the negative electrode, the vertical electric field at this time is 5 V/μm. In this case,

the emitter material to be used is one having the electron emission field larger than 5 V/μm, and the spacing and driving voltage can be determined so as to realize the selected electron emission field.

[0040]

The fibrous carbon made by decomposing a hydrocarbon gas under use of a catalyst is shown in Fig. 11 and Fig. 12 as an example of materials having the threshold electric field of several V/μm.

[0041]

In each figure the left view schematically shows a form observed at the optical microscope level (approximately 1000×), the center view a form observed at the scanning electron microscope (SEM) level (approximately 30,000×), and the right view a form of carbon observed at the transmission electron microscope (TEM) level (approximately 1 million×).

[0042]

As shown in Fig. 11, the form of cylindrical shape of graphen is called a carbon nanotube (a multiple structure of cylinders is called a multiwall nanotube), and the threshold thereof becomes the lowest, particularly, in the structure in which the tube is open at the tip.

[0043]

Fibrous carbons produced at relatively low temperatures under use of a catalyst, the same as this

carbon nanotube, are shown in Fig. 12. A fibrous carbon of this form is comprised of a lamination of graphens (which is thus sometimes called "graphite nanofiber" and the rate of amorphous structure of which increases depending upon the temperature).

[0044]

The carbon nanotubes and graphite nanofibers differ depending upon the type of the catalyst and the temperature of decomposition. It may be possible to select from carbons having both configurations with identical catalyst depending on the temperature or achieve only either of the configurations.

[0045]

All the fibrous carbons have the threshold for the emission of electron in the range of approximately 1 to 10 V/μm and are suitable for the emitter to be used for electron-emitting devices related to the embodiments of the present invention.

[0046]

As the catalyst materials, Fe, Co, and the like are normally used in the formation of the carbon nanotubes, but Pd, Ni and the like can also be used as the nuclei for formation of the fibrous carbons.

[0047]

Particularly, in the case of Pd or Ni, the graphite nanofibers can be produced at low temperatures (temperatures of not less than 450°C). When Fe or Co

is used, the temperature for production of carbon nanotubes needs to be not less than 800°C. Since the production of the graphite nanofiber material using Pd or Ni can be implemented at low temperatures, it is also preferable in terms of influence on the other members and the production cost.

[0048]

Further, in the case of the Pd catalyst, using the property that the oxide thereof is readily reduced by hydrogen at low temperatures (room temperature), it is feasible to use palladium oxide as a nucleation material.

[0049]

By employing the hydrogen reduction treatment of palladium oxide, it became feasible to form the initial aggregated nuclei at relatively low temperatures (200°C or less) without use of thermal aggregation of metal thin film or production and evaporation of ultrafine particles accompanied by a danger of explosion which are conventionally used as ordinary nucleation techniques.

[0050]

The foregoing hydrocarbon gas may be, for example, either of hydrocarbon gases such as ethylene, methane, propane, propylene, and so on, or vapors of organic solvents such as ethanol, acetone, and so on.

[0051]

Next, the inventors also conducted research about a method of forming a high-definition electron beam using the fibrous carbons. The high-definition beam forming method will be described below.

[0052]

In general, the operating voltage Vf of the FE device is determined by the electric field at the tip portion of the emitter, which is derived by the Poisson's equation, and the current density of electron emission current according to a relation called the Fowler-Nordheim equation, using the electric field and a work function at the emitter portion as parameters.

[0053]

As for the electric field necessary for the electron emission, the smaller the distance D between the emitter tip and the gate electrode, or the smaller the radius r of the emitter tip, the stronger the electric field is established.

[0054]

On the other hand, the maximum X-directional size Xd of the electron beam on the anode (for example, the maximum range from the center of the circular beam profile 137 in Fig. 13) is expressed in the form proportional to $\sqrt{(Vf/Va)}$ in simple computation.

[0055]

As apparent from this relation, increase in Vf results in increase in the beam size.

[0056]

From this consideration, the distance D and radius r need to be set as small as possible in order to decrease Vf.

[0057]

Next, let us consider the electric field for extracting electrons (which will be called a "lateral electric field" herein for convenience' sake and the enhancement effect of the electric field by the emitter shape will be ignored herein) and the electric field directed toward the anode (which will be called a "vertical electric field" herein).

[0058]

As described previously, electrons emitted from the emitter are first drawn by the lateral electric field to fly toward the gate and thereafter they are moved up by the vertical electric field to reach the anode directly or through several scatterings.

[0059]

Important points at this time are a ratio of strengths of the lateral electric field and the vertical electric field and the relative position of electron emission point.

[0060]

When the lateral electric field is stronger in order of magnitude than the vertical electric field, most of the electrons emitted fly in trajectories

gradually bent by radial potentials formed by the lateral electric field and directed toward the gate. The electrons colliding with the gate are again emitted because of scattering, and thereafter are repeatedly scattered as spreading on the gate while drawing trajectories similar to ellipses many times and as reducing the number of emitted electrons, before they are captured by the vertical electric field.

[0061]

When the scattered electrons then cross an equipotential line made by the gate potential (which is also called a "stagnation point"), they are moved up by the vertical electric field for the first time.

[0062]

When the lateral electric field and the vertical electric field are approximately equal in strength to each other, the extracted electrons also fly in trajectories bent by the radial potentials, but the binding by the electric field becomes weaker, so that there appear trajectories of electrons captured by the vertical electric field without colliding with the gate.

[0063]

It was verified that with the lateral electric field and vertical electric field approximately equal in strength to each other, as the position of the electron emission point from the emitter was gradually lifted up from the plane to which the gate belonged,

toward the plane to which the anode belonged (see Fig. 6), the emitted electrons could fly in trajectories captured by the vertical electric field without colliding with the gate at all.

[0064]

Research was conducted about the electric field ratios and it was found from the research that, where d represented the distance of the above-mentioned spacing (spacing between the gate electrode and the tip of the emitter electrode), V1 the potential difference (the potential difference between the gate electrode and the emitter electrode) during driving of the device, H the distance between the positive electrode (anode) and the substrate (device), and V2 (Va) the potential difference between the positive electrode (anode) and the negative electrode (emitter electrode), the extracted electrons drew the trajectories colliding with the gate when the lateral electric field was about 50 or more times stronger than the vertical electric field.

[0065]

A height s causing no scattering (which is defined by a distance from the highest part of the gate to the lowest part of the emitter) is dependent upon the ratio of the vertical electric field and the lateral electric field and the height becomes lower with decrease in the vertical-lateral electric field ratio (strength of the

vertical electric field/strength of the lateral electric field) and becomes higher with increase in the lateral electric field.

[0066]

A practical fabrication range of the height s is not less than 10 nm nor more than 10 μm.

[0067]

In the conventional configuration, since the gate and the emitter were formed at the same height on the same plane and since the lateral electric field was stronger by one or more figures than the vertical electric field, there was the strong tendency that the number of extracted electrons into the vacuum decreased because of the collision with the gate.

[0068]

Further, in the conventional configuration, since the thickness and width of the gate electrode and the relative positions of the gate, emitter, and anode were determined for the purpose of enhancing the intensity of the lateral electric field, the electron distribution on the anode became expanded.

[0069]

As described previously, in order to make small the distribution of electrons reaching the anode (spot diameter), it is necessary to consider 1) decreasing Vf, 2) aligning the extraction directions of electrons, 3) trajectories of electrons, and, further, in the case

involving the scattering on the gate, 4) the scattering mechanisms of electrons (particularly, elastic scattering).

[0070]

In this way, the configurations of the present invention are the result of exhaustive examination based on the above-mentioned ideas for the purpose of the size reduction of the electron distribution and improvement in the efficiency.

[0071]

The electron-emitting devices related to the embodiments of the present invention mentioned above will be described below in further detail with reference to the drawings. Fig. 1 contains schematic views showing the electron-emitting device related to the embodiments of the present invention, wherein (A) is a plan view thereof and (B) a cross-sectional view along A-A.

[0072]

In Fig. 1, numeral 1 designates an electrically insulating substrate, 2 an extraction electrode (also called "gate electrode" or "second electrode"), 3 a negative electrode (also called "first electrode"), 4 fibrous carbons being an emitter material, 5 a conductive layer and 6 a second conductive layer.

[0073]

Here the conductive layer 5 is made of a material

permitting the fibrous carbons 4 to grow thereon, while the second conductive layer 6 is made of a material not permitting the fibrous carbons 4 to grow thereon.

[0074]

The electrically insulating substrate 1 can be either of laminations in which SiO_2 is laid by sputtering or the like on a well-cleaned surface of either of silica glass, glasses partly replaced with K or the like while reducing the impurity content of Na and others, soda lime glass, silicon substrates, etc. insulating substrates of ceramics such as alumina or the like, and so on.

[0075]

The extraction electrode 2 and the negative electrode 3 are electrically conductive and are made by either of the ordinary vacuum film-forming technologies such as vacuum evaporation, sputtering, and the like, or the photolithography technology.

[0076]

The materials of the extraction electrode 2 and the negative electrode 3 are adequately selected, for example, from carbon, metals, nitrides of metals, carbides of metals, borides of metals, semiconductors, and metal semiconductors compounds.

[0077]

The thicknesses of the extraction electrode 2 and the negative electrode 3 are set in the range of

several ten nm to several ten μm. Preferably, they are desirably made of either of heat resistant materials such as carbon, metals, nitrides of metals, and carbides of metals.

[0078]

When there is a worry that a potential drop or the like can occur because of the small thickness of the electrodes or when such devices are used in a matrix array, a low-resistant metal material for wiring is sometimes used in portions not associated with the emission of electrons as occasion may demand.

[0079]

As mentioned above, in comparison of electric field intensities between the electron emission field of the cathode material used (the lateral electric field) and the vertical electric field necessary for the formation of image, the gap between the extraction electrode 2 and the negative electrode 3 (the width of the gap) and the driving voltage may be determined so that the electron emission field becomes approximately 1 times to 50 times stronger than the vertical electric field.

[0080]

The fibrous carbons are preferably those obtained by forming nuclei with use of a catalyst and growing the fibrous carbons from the nuclei by thermal decomposition, especially such as carbon nanotubes and

graphite nanofibers.

[0081]

The material of the conductive layer 5 allowing the growth of fibrous carbons 4 may use a mixture of Ti and an oxide thereof resulting from partial oxidation of Ti, or an oxide semiconductor of Ti; or a mixture of Zr and an oxide thereof resulting from partial oxidation of Zr, or an oxide semiconductor of Zr; or a mixture of Nb and an oxide thereof resulting from partial oxidation of Nb, or an oxide semiconductor of Nb, as described previously.

[0082]

These oxides of Ti, Zr, and Nb are stoichiometrically insulators, but weakly oxidized substances thereof or suboxides thereof possess a number of defects inside and thus form semiconductors of the oxygen deficient type or the like.

[0083]

Baking Pd on the layer of Ti, Zr, or Nb at the temperature of about 300°C for about several ten minutes to form palladium oxide and oxidizing the layer of Ti, Zr, or Nb as well. The baking temperature and time of this level, however, do not oxidize the entire conductive layer materials, though depending upon the thickness of the materials of the conductive layer, but oxidize only the surface. Since such oxide has the semiconductorlike nature as described above, the

conductive layer 5 thus formed results in possessing electrical conductivity.

[0084]

The second layer 6 on which no growth of fibrous carbon occurs through the catalyst particles is comprised so as to cover the region except for the side face of the conductive layer 5 on which growth of fibrous carbon occurs through the catalyst particles on the extraction electrode 2 side.

[0085]

As a result, only the side wall of the conductive layer 5 on which growth of fibrous carbon occurs on the extraction electrode 2 side is exposed, and thus the fibrous carbons 4 grow through the catalyst particles only on the side wall on the extraction electrode 2 side in the subsequent step of growth of fibrous carbons.

[0086]

If the device should not have the conductive layer 6 on which the fibrous carbons do not grow through the fine catalyst particles, the fibrous carbons would grow over the entire surface of the conductive layer 5 on which the fibrous carbons can grow through the fine catalyst particles. In this case, the fibrous carbons apart from the gate electrode 2 would be involved in emission of electrons, though it is a little, and such electrons could disturb the beam profile and uniformity.

[0087]

In contrast with it, in the electron-emitting device according to the present embodiment, there exists no fibrous carbons on the side walls except for the side wall on the extraction electrode 2 side, and it is thus feasible to prevent the disturbance of the beam profile and uniformity.

[0088]

The position of the electron emission point in the emitter region and the operation thereof will be described below referring to Fig. 6 and Fig. 7.

[0089]

The instant device having the gap length d of several μm was placed in a vacuum chamber 60, as shown in Fig. 6, and then the interior thereof was evacuated well down to about 10^{-4} Pa by an vacuum pump 65. While the positive electrode (hereinafter referred to as an anode) 61 was set at the position of the height H of several millimeters from the substrate 1, a high voltage Va of several kV was applied from a voltage source.

[0090]

A fluorescent member 62 with an electroconductive film coating thereon was placed on the anode 61.

[0091]

A pulse voltage of about several ten V was applied as the driving voltage Vf to be applied to the device

to measure the device current If and electron emission current Ie.

[0092]

At this time, equipotential lines 63 are formed as shown, and the electric field is most concentrated at the part indicated by point 64 closest to the anode 61 among the fibrous carbons 4 of the electron-emitting material and inside the gap.

[0093]

It is speculated that electrons are emitted from the site where the electric field is most concentrated in the electron-emitting material located in the vicinity of this field concentrating point 64.

[0094]

The Ie characteristic of the device was that shown in Fig. 7. Namely, Ie demonstrated a sudden rise from about half of the applied voltage, and If, not shown, was similar to the characteristic of Ie but considerably smaller than Ie.

[0095]

Based on this principle, an electron source and an image-forming apparatus comprised of a plurality of electron-emitting devices according to the embodiment of the present invention will be described hereinafter with reference to Fig. 8 to Fig. 10. Fig. 8 is a schematic plan view of electron source according to an embodiment of the present invention, Fig. 9 a

perspective view of an image-forming apparatus, partly broken, according to an embodiment of the present invention, and Fig. 10 a block diagram of an image-forming apparatus according to an embodiment of the present invention.

[0096]

In Fig. 8, numeral 81 denotes an electron source substrate, 82 X-directional wires, and 83 Y-directional wires. Numeral 84 denotes electron-emitting devices according to the embodiment of the present invention, and 85 interconnections.

[0097]

In this configuration the placement of plural electron-emitting devices 84 is accompanied by increase in the capacitance of the devices, and there arises a problem that in the matrix wiring shown in Fig. 8, waves become dull because of the capacitance component, so as to fail to attain expected gradation even with application of short pulses according to pulse width modulation.

[0098]

In order to avoid it, it is preferable to employ a structure for reducing the increase of the capacitance component except for that in the electron emission section, for example, by placing an interlayer electric film (rear plate 91) right next to the electron emission section, as shown in Fig. 9.

[0099]

In Fig. 8, the m X-directional wires 82 consist of DX_1, DX_2,..., DX_m and are made of an aluminum based wiring material in the thickness of about 1 μm and in the width of 300 μm by evaporation. However, the material, thickness, and width of the wires are properly designed according to respective cases.

[0100]

On the other hand, the Y-directional wires 83 consist of n wires of DY_1, DY_2,..., DY_n 0.5 μm thick and 100 μm wide and are made in similar fashion to the X-directional wires 82.

[0101]

An interlayer dielectric film not shown is disposed between these m X-directional wires 82 and n Y-directional wires 83, so as to electrically isolate them from each other (where m and n are positive integers).

[0102]

The unrepresented interlayer dielectric film is made of SiO_2 in the thickness of about 0.8 μm by sputtering or the like.

[0103]

The interlayer dielectric film is formed in the desired shape over the entire surface or in part of the substrate 81 after formation of the X-directional wires 82, and the thickness of the interlayer dielectric film

is determined so that the device capacitance per device is not more than 1 pF and the device withstand voltage 30 V in the present embodiment, particularly, in order to resist the potential difference at intersections between the X-directional wires 82 and the Y-directional wires 83. The X-directional wires 82 and Y-directional wires 83 are drawn out as respective external terminals.

[0104]

Pairs of electrodes (not shown) making up the electron-emitting devices 84 according to the embodiment of the present invention are electrically connected by the m X-directional wires 82, n Y-directional wires 83, and interconnections 85 of an electroconductive metal or the like.

[0105]

Connected to the X-directional wires 82 is an unrepresented scanning signal applying means for applying a scanning signal for selection of a row of electron-emitting devices 84 according to the embodiment of the present invention, arrayed in the X-direction.

[0106]

Connected to the Y-directional wires 83 on the other hand is an unrepresented modulation signal generating means for modulating each column of electron-emitting devices 84 according to the

embodiment of the present invention, arrayed in the Y-direction, according to an input signal.

[0107]

The driving voltage applied to each electron-emitting device is supplied as a difference signal between a scanning signal and a modulation signal applied to the device. In the embodiment of the present invention, electrical connection is established so that the Y-directional wires are at a higher potential while the X-directional wires at a lower potential. This connection yields the beam converging effect, which is a feature of the embodiment of the present invention.

[0108]

In the above configuration, the individual devices can be selected to be driven independently by use of the simple matrix wiring.

[0109]

An image-forming apparatus constructed by use of the electron source of this simple matrix configuration will be described referring to Fig. 9. Fig. 9 shows a display panel of the image-forming apparatus wherein soda lime glass is used as a material of a glass substrate.

[0110]

In Fig. 9, numeral 81 designates an electron source substrate loaded with a plurality of electron-

emitting devices, 91 a rear plate to which the electron source substrate 81 is fixed, and 96 a face plate wherein a florescent film 94, a metal back 95, etc. are formed on an internal surface of glass substrate 93. Numeral 92 denotes a support frame, and the rear plate 91 and face plate 96 are coupled to this support frame 92 with frit glass or the like. Numeral 97 represents an envelope which is sealed by baking it in the temperature range of 450°C in vacuum for ten minutes.

[0111]

Numeral 84 indicates the electron emission regions and numerals 82 and 83 denote the X-directional wires and Y-directional wires, respectively, which are connected to the pairs of device electrodes of the electron-emitting devices according to the embodiment of the present invention.

[0112]

The envelope 97 is composed of the face plate 96, the support frame 92, and the rear plate 91, as described above. When an unrepresented support called a spacer is interposed between the face plate 96 and the rear plate 91, the envelope 97 can be constructed with sufficient strength against the atmospheric pressure.

[0113]

The metal back 95 can be made in such a way that after production of the fluorescent film, the internal

surface of the fluorescent film is subjected to a smoothing process (normally called "filming") and thereafter Al is deposited thereon by vacuum evaporation or the like.

[0114]

The face plate 96 is further provided with a transparent electrode (not shown) on the outer surface side of the fluorescent film 94, in order to further enhance the electrical conductivity of the fluorescent film 94.

[0115]

During the aforementioned sealing operation, in the color display case, correspondence has to be made between respective color phosphors and electron-emitting devices and thus sufficient alignment is essential.

[0116]

Next, a scanning circuit 102 shown in Fig. 10 will be described below. This circuit is provided with M switching devices inside (schematically indicated by S1 to Sm in the figure). Each switching device selects either an output voltage of a dc voltage source Vx or 0 V (the ground level) to be electrically connected to a terminal Dx1 to Dxm of display panel 101.

[0117]

Each switching device of S1 to Sm operates based on a control signal Tscan from a control circuit 103

and can be constructed, for example, of a combination of switching devices such as FETs.

[0118]

The dc voltage source Vx is set to output such a constant voltage that the driving voltage applied to non-scanned devices is not more than the electron emission threshold voltage, based on the characteristics of the electron-emitting devices (electron emission threshold voltage) according to the embodiment of the invention, in the case of the present example.

[0119]

The control circuit 103 has the function of matching operations of respective portions so as to implement appropriate display based on image signals supplied from the outside. The control circuit 103 generates control signals of Tscan, Tsft, and Tmry to the respective portions, based on a synchronizing signal Tsync supplied from a synchronizing signal separating circuit 106.

[0120]

The synchronizing circuit 106 is a circuit for separating the synchronizing signal component and luminance signal component from a TV signal of the NTSC system supplied from the outside, and can be composed of an ordinary frequency separating (filter) circuit or the like.

[0121]

Although the synchronizing signal separated by the synchronizing signal separating circuit 106 consists of a vertical synchronizing signal and a horizontal synchronizing signal, it is illustrated as a Tsync signal herein for convenience' sake of description. The luminance signal component of an image separated from the aforementioned TV signal is indicated as a DATA signal for convenience' sake. This DATA signal is entered into a shift register 104.

[0122]

The shift register 104 performs serial-parallel conversion for each line of an image with reception of DATA signals serially supplied in time sequence and operates based on the control signal Tsft sent from the control circuit 103. Namely, the control signal Tsft can also be called as a shift clock for the shift register 104.

[0123]

Data of one line of an image after the serial-parallel conversion (corresponding to driving data for N devices out of the electron-emitting devices) is outputted as N parallel signals of Id1 to Idn from the shift register 104.

[0124]

A line memory 105 is a storage device for storing the data of one line of an image for a required time

and is configured to store the contents of Id1 to Idn properly according to the control signal Tmry sent from the control circuit 103. The stored contents are outputted as I'd1 to I'dn to enter a modulation signal generator 107.

[0125]

The modulation signal generator 107 is a signal source for appropriately modulating each of the electron-emitting devices of the present embodiment according to each of the image data I'd1 to I'dn, and output signals therefrom are applied through terminals Doy1 to Doyn to the electron-emitting devices of the present embodiment in the display panel 101.

[0126]

As described previously, the electron-emitting devices according to the embodiment of the present invention have the following basic characteristics concerning the emission current Ie.

[0127]

Namely, there is the definite threshold voltage Vth for the emission of electrons and electrons are emitted only when a voltage not less than Vth is applied.

[0128]

At voltages not less than the electron emission threshold, the emission current also varies according to variation in the applied voltage to the devices.

For this reason, when the pulse voltage is applied to the instant devices, for example, electrons are not emitted with application of a voltage not more than the electron emission threshold but an electron beam is outputted with application of a voltage not less than the electron emission threshold.

[0129]

On that occasion, the intensity of the output electron beam can be controlled by varying the peak height Vm of pulses. It is also possible to control the total charge amount of the output electron beam by changing the width Pw of pulses.

[0130]

Accordingly, either of the voltage modulation method, the pulse width modulation method, etc. can be employed as a method of modulating the electron-emitting devices according to input signals. For carrying out the voltage modulation method, the modulation signal generator 107 can be a circuit of the voltage modulation method configured to generate voltage pulses of a fixed length and modulate peak heights of pulses adequately according to input data.

[0131]

For carrying out the pulse width modulation method, the modulation signal generator 107 can be a circuit of the pulse width modulation method configured to generate voltage pulses of a fixed peak height and

modulate widths of the voltage pulses adequately according to input data.

[0132]

The shift register 104 and the line memory 105 are of the digital signal type.

[0133]

The modulation signal generator 107 is, for example, a D/A converting circuit and an amplifying circuit or the like is added thereto as occasion demands. In the case of the pulse width modulation method, the modulation signal generator 107 is, for example, a circuit consisting of a combination of a fast oscillator and a counting device (counter) for counting the number of waves from the oscillator with a comparing device (comparator) for comparing an output value of the counter with an output value of the memory.

[0134]

The configuration of the image-forming apparatus stated herein is just an example of the image-forming apparatus to which the present invention is applicable, and a variety of modifications can be made based on the technical concept of the present invention. The input signals were of the NTSC system, but the input signals are not limited to this system; for example, it is also possible to employ the PAL system, SECAM system, etc., and systems of TV signals consisting of a larger number of scanning lines than them (for example, high-

definition TV systems including the MUSE system).

[0135]

[Examples]

More specific examples based on the above embodiments will be described below in detail.

[0136]

(Example 1)

In the present example, the basic configuration is comprised of the configuration shown in Figs. 1A and 1B as described in the above-stated embodiment.

[0137]

The steps for fabrication of the electron-emitting device according to the present example will be described below in detail with reference to Fig. 5.

[0138]

(Step 1)

After a silica substrate used as the substrate 1 was cleaned well, a Ti layer 5 nm thick and a Pt layer 500 nm thick, not shown, were first consecutively evaporated over the entire surface of the substrate by sputtering, in order to form the extraction electrode 2 and the negative electrode 3.

[0139]

Then a resist pattern was formed with an unrepresented positive photoresist (AZ1500 available from Clariant) by the photolithography process.

[0140]

Using the patterned photoresist as a mask, the Pt layer and Ti layer were then subjected to dry etching with Ar gas to pattern the extraction electrode 2 and the negative electrode 3 with the electrode gap (the width of gap) of 5 μm (a state shown in (A) of Fig. 5).

[0141]

The patterning of a thin film or a resist by the photolithography process, film formation, lift-off, etching, etc. will be referred to hereinafter simply as patterning.

[0142]

(Step 2)

Then an unrepresented Cr layer was deposited in the thickness of about 100 nm over the entire surface of the substrate by electron beam evaporation and the positive photoresist (AZ1500 available from Clariant) was patterned thereon.

[0143]

Using the patterned photoresist as a mask, a region (100 μm × 80 μm) to cover the conductive layer for growth of fibrous carbons through the catalyst particles was then formed on the negative electrode 3 and the Cr layer in the opening portion was removed with a cerium nitrate based etchant.

[0144]

Then a Ti layer for growth of fibrous carbons through the catalyst particles was evaporated in the

thickness of 50 nm by sputtering.

[0145]

Then the unnecessary Ti layer and resist were removed simultaneously (lift-off method), thereby forming the Ti conductive layer 5 (a state shown in (B) of Fig. 5).

[0146]

(Step 3)

By the patterning similar to step 2, the Ti conductive layer 5 was covered by the Ta conductive layer 6 (140 μm × 100 μm) not permitting the growth of fibrous carbons through the catalyst particles, so as to expose only the side wall of the Ti conductive layer 5 on the extraction electrode side (a state shown in (C) of Fig. 5).

[0147]

(Step 4)

In the subsequent step, an unrepresented Cr layer of about 100 nm was patterned so as to expose only side walls of the Pt/Ti layers (equivalent of the negative electrode 3), the Ti conductive layer 5, and the Ta conductive layer 6 on the extraction electrode side.

[0148]

Then a complex solution obtained by adding isopropyl alcohol or the like to a Pd complex was applied onto the entire surface of the substrate by spin coating.

[0149]

After the application, a heat treatment was carried out at 300°C in the atmosphere to form a palladium oxide layer in the thickness of about 10 nm over the entire surface. Thereafter, Cr was removed with the cerium nitrate based etchant to lift off the unnecessary palladium oxide thereby, thus forming the patterned palladium oxide layer.

[0150]

After evacuation of atmosphere, the substrate was heated to 200°C to carry out a heat treatment in a 2% hydrogen stream diluted with nitrogen. At this stage the catalyst particles 52 were formed in particle diameters of about 3 to 10 nm on the wall surfaces in the surface of device. The density of the particles at this time was estimated as about 10^{11} to 10^{12} particles/cm^2 (a state shown in (D) of Fig. 5).

[0151]

(Step 5)

In the subsequent step, a heat treatment was conducted at 500°C in a 0.1% ethylene stream diluted with nitrogen for ten minutes. The resultant was observed with the scanning electron microscope and it was verified therefrom that a number of fibrous carbons 4 extending in fibrous shape as bent were formed in the diameters of about 10 nm to 25 nm only on the wall surface of the Ti conductive layer 5 permitting the

growth of fibrous carbons through the catalyst particles among the catalyst particles on the wall surfaces.

[0152]

The thickness of the fibrous carbons 4 at this time was about 500 nm. No fibrous carbon 4 was recognized on the wall surfaces of the Pt layer (negative electrode 3) and the Ta conductive layer 6 not permitting the growth of fibrous carbons through the catalyst particles (a state shown in (E) of Fig. 5).

[0153]

The electron-emitting device fabricated as described above was set in the vacuum chamber 60 as shown in Fig. 6 and the interior thereof was evacuated well down to the vacuum of 2×10^{-5} Pa by the evacuator 65.

[0154]

Then the anode voltage of Va = 10 kV was applied to the positive electrode (anode) 61 H = 2 mm apart from the device, as shown in Fig. 6. At this time, while the pulse voltage consisting of the driving voltage Vf = 20 V was applied to the device, the flowing device current If and electron emission current Ie were measured.

[0155]

The If and Ie characteristics of the device were those shown in Fig. 7. Namely, Ie demonstrated a

sudden increase from about half of the applied voltage and the electron emission current Ie of about 1 μA was measured at Vf of 15 V. On the other hand, If was similar to the characteristic of Ie but values thereof were a figure or more smaller than those of Ie.

[0156]

The resultant beam was approximately of a rectangular shape slender in the Y-direction and short in the X-direction.

[0157]

Beam widths were measured under such conditions that Vf was fixed at 15 V, the anode distance was fixed at H of 2 mm, the anode voltage was either of 5 kV and 10 kV, and the gap (width of gap) was either of 1 μm and 5 μm, and the results are presented in Table 1 below.

[0158]

[Table 1]

	Va = 5 kV	Va = 10 kV
Gap: 1 μm	X-direction 60 μm Y-direction 170 μm	X-direction 30 μm Y-direction 150 μm
Gap: 5 μm	X-direction 93 μm Y-direction 170 μm	X-direction 72 μm Y-direction 150 μm

It was feasible to change the electric field necessary for the driving, by varying the growth conditions. Particularly, an average particle size of

Pd particles obtained by the reduction treatment of palladium oxide is associated with the diameters of fibers formed by the growth thereafter.

[0159]

The mean particle size of Pd particles was able to be controlled by the Pd concentration of the coated Pd complex and the rotational speed of the spin coating.

[0160]

The carbon fibers of this device were observed with the transmission electron microscope and they were of the layered structure of graphens as shown on the right side of Fig. 12. The layer intervals of the graphens (in the direction of C-axis) were unclear at the temperature as low as about 500°C, and were 0.4 nm. As the temperature increased, the grating intervals became clearer, and at 700°C the intervals were 0.34 nm, which was close to 0.335 nm of graphite.

[0161]

By employing the configuration of the electron-emitting device according to the present example, as described above, the electron-emitting device was realized with the properties of the reduced capacitance and driving voltage, the high efficiency, and the small beam size.

[0162]

(Example 2)

The electron-emitting device according to Example

2 will be described below with reference to Fig. 2. Fig. 2 shows schematic views of the electron-emitting device according to Example 2 of the present invention, wherein (A) is a plan view thereof and (B) a cross-sectional view along AA in (A).

[0163]

The electron-emitting device in the present example was fabricated in the same manner as in Example 1 in the structure and others except that the thickness of the extraction electrode 2 in Example 1 was changed to 200 nm, and If and Ie were measured therewith.

[0164]

In the structure of the instant device, the thickness of the negative electrode 3 was larger than the thickness of the extraction electrode 2 whereby the electron emission position was able to be set surely at a higher position (on the anode side) from the extraction electrode 2.

[0165]

This configuration decreased the number of electrons flying in the trajectories colliding with the gate, so as to be able to prevent the phenomena of decrease of efficiency and increase of the beam size.

[0166]

As a consequence, in the structure of the present device, the electron emission current Ie of about 1 μA was also measured at Vf of 20 V. On the other hand, If

was similar to the characteristic of Ie but values thereof were two figures smaller than those of Ie. The beam sizes at this time were also approximately the same as in Table 1.

[0167]

By employing the configuration of the electron-emitting device according to the present example, as described above, the electron-emitting device was realized with the properties of the reduced capacitance and driving voltage, the high efficiency, and the small beam size.

[0168]

(Example 3)

The electron-emitting device according to Example 3 will be described with reference to Fig. 3. Fig. 3 shows schematic views of the electron-emitting device according to Example 3 of the present invention, wherein (A) is a plan view thereof and (B) a cross-sectional view along AA in (A).

[0169]

In the present example, the conductive layer 5 was formed up to an almost middle point of the gap across the gap from on the surface of the negative electrode 3 to on the surface of the substrate in step 2 in Example 1, whereby the gap distance was made to about half.

[0170]

Since in the present device the gap distance was

smaller than in Example 1, the electric field was about two times stronger than in Example 1. This permitted the voltage for the driving to be reduced to about 8 V. Since the conductive layer 5 was used as an electrical connection layer for the fibrous carbons 4, it became feasible to emit electrons stably from the fibrous carbons 4 in the gap.

[0171]

By employing the configuration of the electron-emitting device according to the present example, as described above, the electron-emitting device was realized with the properties of the reduced capacitance and driving voltage, the high efficiency, and the small beam size.

[0172]

(Example 4)

The electron-emitting device according to Example 4 will be described with reference to Fig. 4. Fig. 4 shows schematic views of the electron-emitting device according to Example 4 of the present invention, wherein (A) is a plan view thereof and (B) a cross-sectional view along AA in (A).

[0173]

The present example is different as follows in step 1 and step 2 described in foregoing Example 1, and the other steps of the present example are the same as in Example 1.

[0174]

(Step 1)

After the silica substrate used as the substrate 1 was cleaned well, consecutive evaporation by sputtering was conducted to form a Ti layer 5 nm thick and a Pt layer 500 nm thick as the cathode (emitter) electrode 3 and a Ti layer 100 nm thick as the conductive layer 5 permitting the growth of fibrous carbons.

[0175]

Then a resist pattern was formed with the positive photoresist (AZ1500 available from Clariant) by the photolithography process.

[0176]

Using the patterned photoresist as a mask, the Ti conductive layer 5 was then etched by dry etching with CF_4 and thereafter the Pt and Ti layers were etched by dry etching with Ar, thereby forming the negative electrode 3.

[0177]

Using the negative electrode 3 as a mask, the silica substrate was etched to the depth of about 500 nm with mixed acids consisting of hydrofluoric acid and ammonium fluoride.

[0178]

Subsequently, a Ti layer 5 nm thick and a Pt layer 30 nm thick were again consecutively evaporated as the extraction electrode 2 by sputtering. The photoresist

on the negative electrode 3 was removed and thereafter a resist pattern was again formed for formation of the gate electrode shape with the positive photoresist (AZ1500 available from Clariant).

[0179]

Using the patterned photoresist as a mask, the Pt layer and the Ti layer were then etched by dry etching with Ar to form the extraction electrode 2 in such structure that a step difference between steps acted as a gap.

[0180]

Then a resist pattern was formed on the cathode and fine particles of Ni were formed in the thickness of about 5 nm by resistance heating evaporation with good straight-ahead nature. After that, an oxidation treatment was carried out at 350°C for 30 minutes. The steps after this step were the same as those in Example 1.

[0181]

The configuration of this device permitted formation of a finer gap and made it feasible to emit electrons from about 6 V.

[0182]

Since the height of the electron-emitting material (film thickness) was large, electrons were not emitted only from the upper part of the film but were also emitted from the middle point, so as to be able to

prevent the decrease of efficiency and the increase of the beam size due to the collision of electrons with the gate electrode.

[0183]

(Example 5)

An image-forming apparatus comprised of a plurality of electron-emitting devices according to the above examples will be described.

[0184]

The electron-emitting devices of Example 1 were arrayed in a matrix pattern as shown in Fig. 8, thus completing the electron source substrate 81.

[0185]

Using this electron source substrate, the fluorescent member was placed on the positive electrode (anode) at the distance of 2 mm above the electron-emitting devices after alignment, thus fabricating the image-forming apparatus shown in Fig. 9.

[0186]

When the apparatus was driven by the pulse voltage of Vf = 20 V and Va = 10 kV, the properties similar to those in Example 1 were also yielded in the image-forming apparatus.

[0187]

[Effect of the Invention]

According to the present invention, as described above, the fibrous carbons are grown only on the side

wall surface of the conductive layer on the extraction electrode side, whereby it is feasible to decrease electrons emitted from the other surfaces than the conductive layer, to enhance the electron emission efficiency, and to improve convergence of trajectories of emitted electrons.

[0188]

When the electron-emitting devices superior in the electron emission efficiency and in the convergence of electron trajectories as described are applied to the electron source, the electron source can be realized with high quality. When this electron source is applied to the image-forming apparatus, the image-forming apparatus can implement formation of higher definition images.

[Brief Description of the Drawings]

[Fig. 1] Schematic views showing an electron-emitting device according to an embodiment and Example 1 of the present invention.

[Fig. 2] Schematic views showing another electron-emitting device according to Example 2 of the present invention.

[Fig. 3] Schematic views showing still another electron-emitting device according to Example 3 of the present invention.

[Fig. 4] Schematic views showing still another electron-emitting device according to Example 4 of the

present invention.

[Fig. 5] Step diagrams for production of the electron-emitting device according to Example 1 of the present invention.

[Fig. 6] A diagram for explaining the operation of the electron-emitting device.

[Fig. 7] A characteristic diagram of the fundamental operation of the electron-emitting device.

[Fig. 8] A schematic plan view of an electron source according to an embodiment of the present invention.

[Fig. 9] A perspective view of an image-forming apparatus, partly broken, according to an embodiment of the present invention.

[Fig. 10] A block diagram of an image-forming apparatus according to an embodiment of the present invention.

[Fig. 11] A schematic structure diagram of fibrous carbons (carbon nanotubes).

[Fig. 12] A schematic structure diagram of fibrous carbons (graphite nanofibers).

[Fig. 13] A schematic structure diagram of the vertical FE configuration according to the prior art.

[Fig. 14] A schematic structure diagram of the lateral FE configuration according to the prior art.

[Description of Reference Numerals or Symbols]

1 Substrate

2 Extraction electrode

3 Negative electrode

4 Fibrous carbon

5 Conductive layer

6 Second conductive layer

52 Catalyst particle

60 Vacuum chamber

61 Anode

62 Fluorescent member

63 Equipotential line

65 Evacuator

81 Substrate

82 X-directional wire

83 Y-directional wire

84 Electron-emitting device

85 Interconnection

91 Rear plate

92 Support frame

93 Glass substrate

94 Fluorescent film

95 Metal back

96 Face plate

97 Envelope

101 Display panel

102 Scanning circuit

103 Control circuit

104 Shift register

105 Line memory

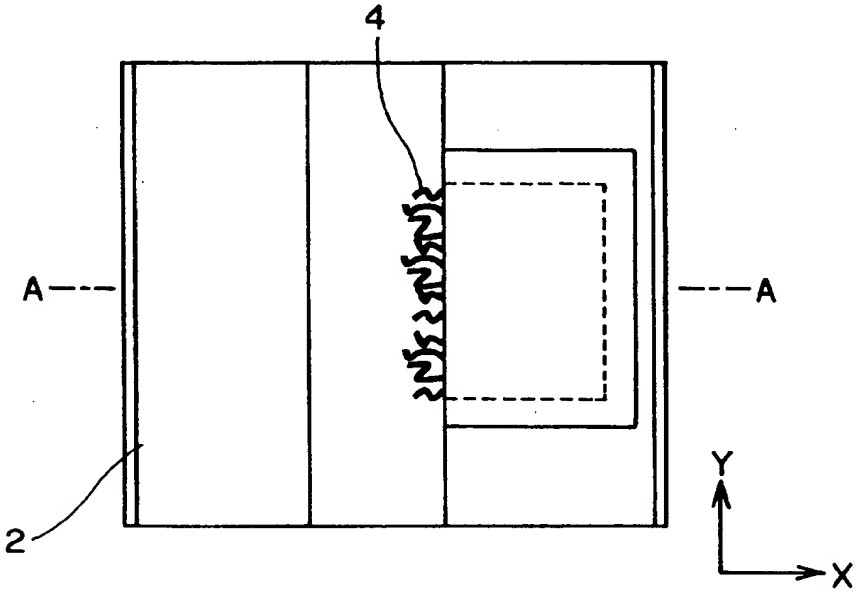
106 Synchronizing signal separating circuit

107 Modulation signal generator

5

【書類名】　図面　(Name of the Document) Drawings

【図１】　Fig. 1



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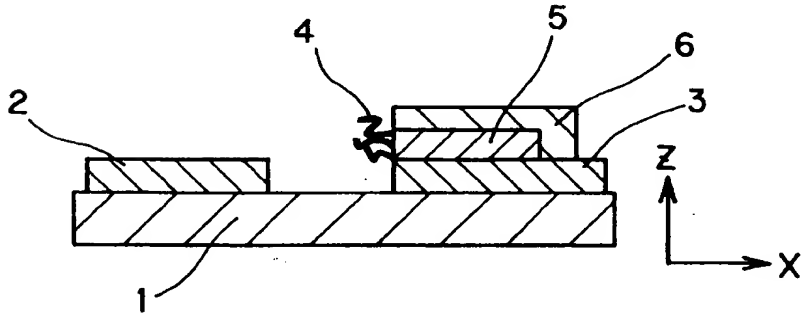
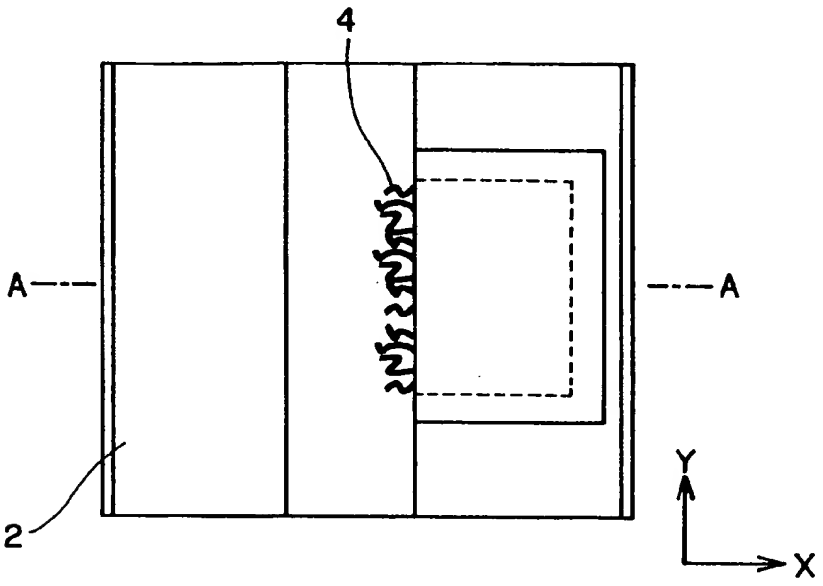


(B)

【図２】　Fig. 2



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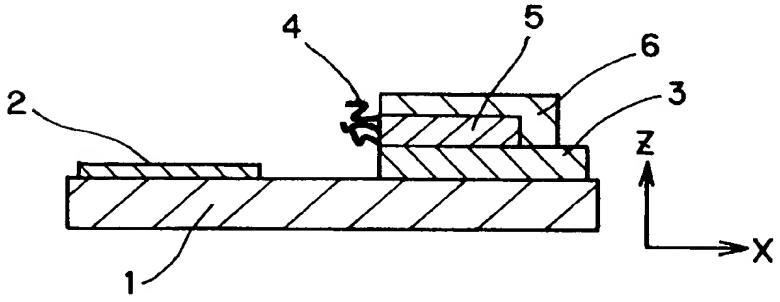
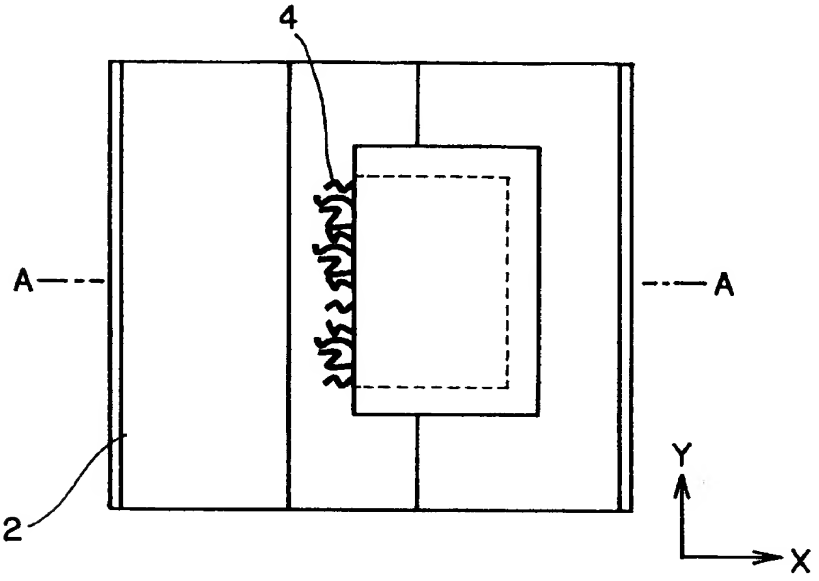


(B)

【図３】 Fig. 3



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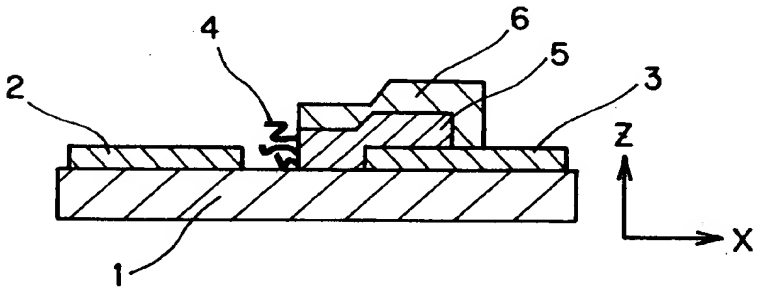
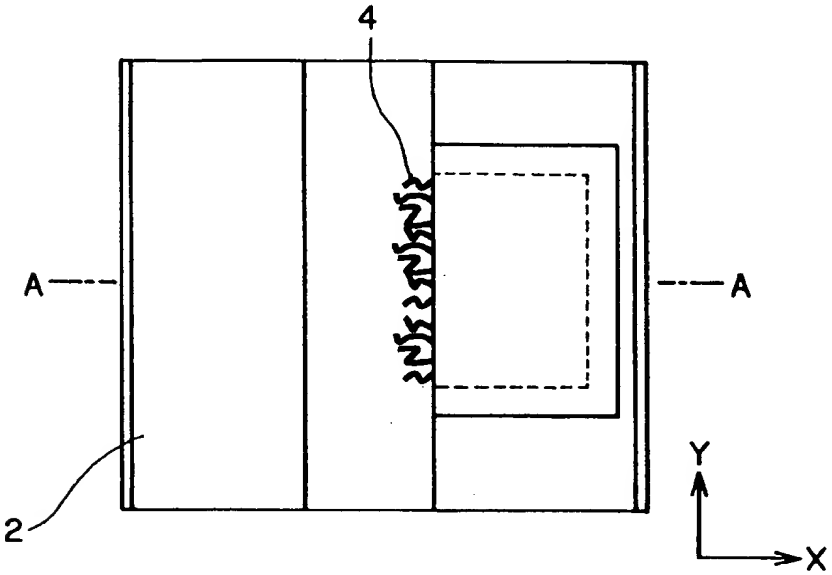


(B)

【図４】　Fig. 4



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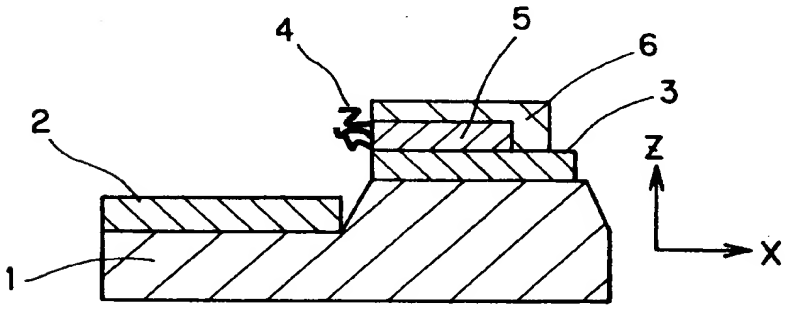
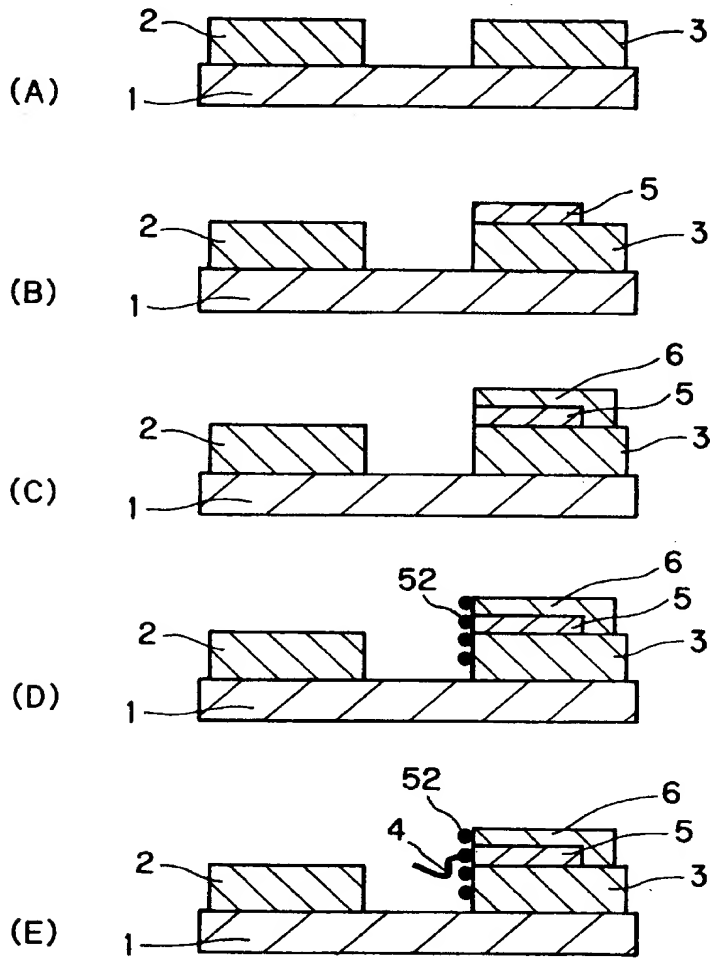
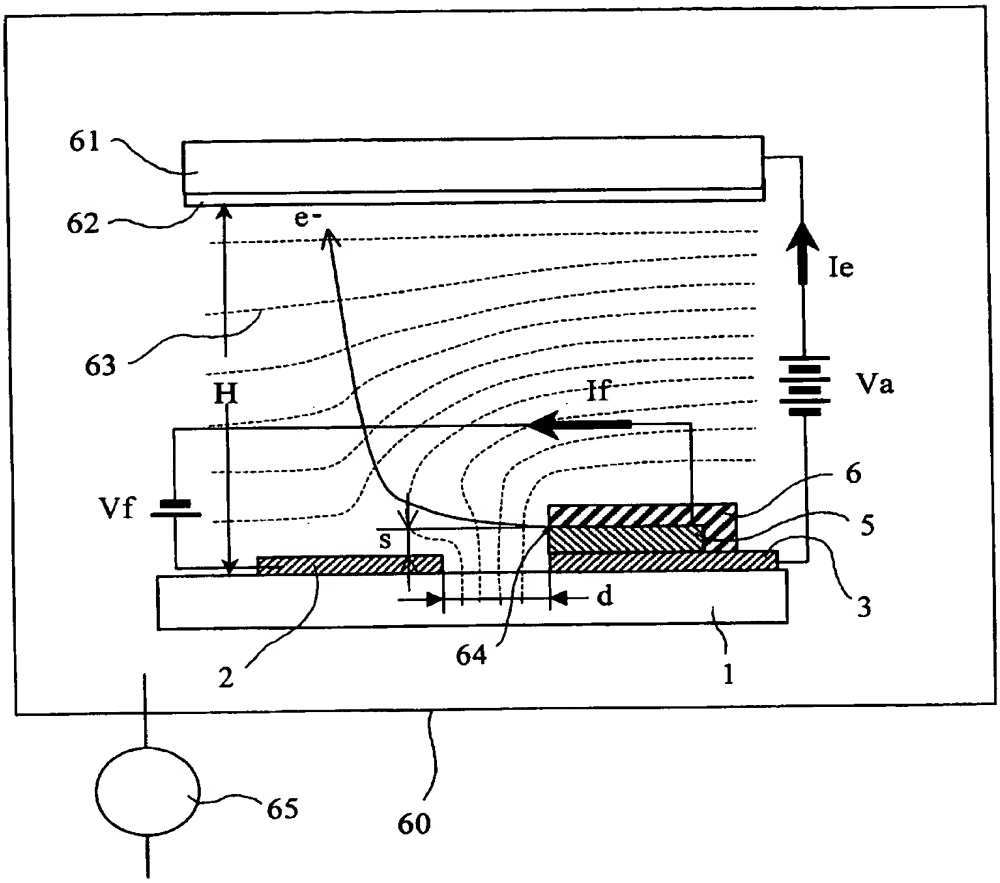


(B)

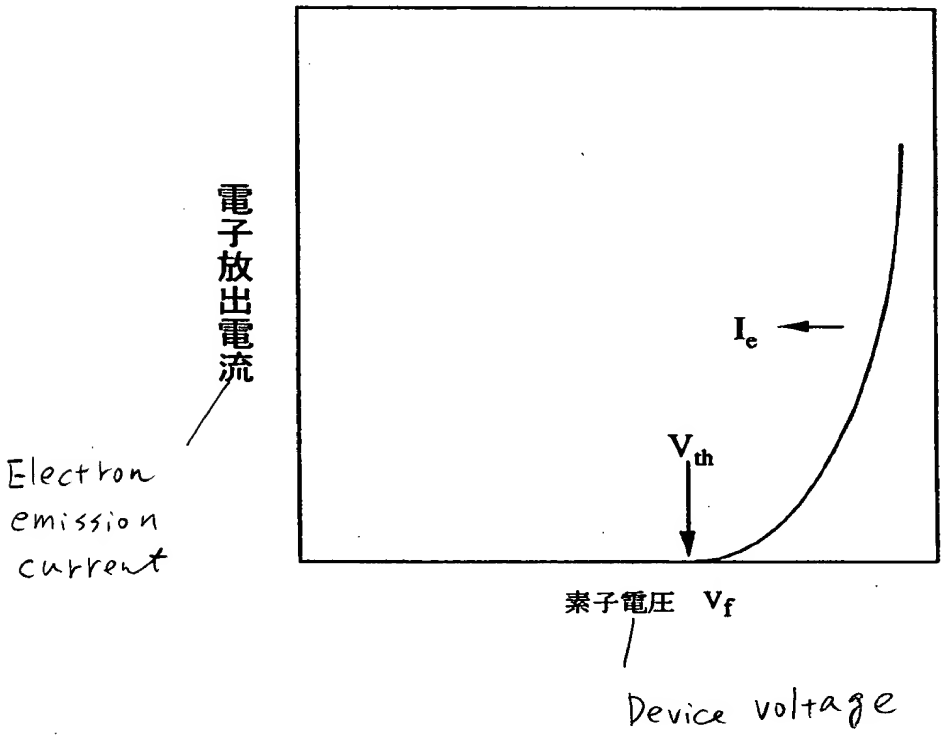
【図５】　Fig. 5



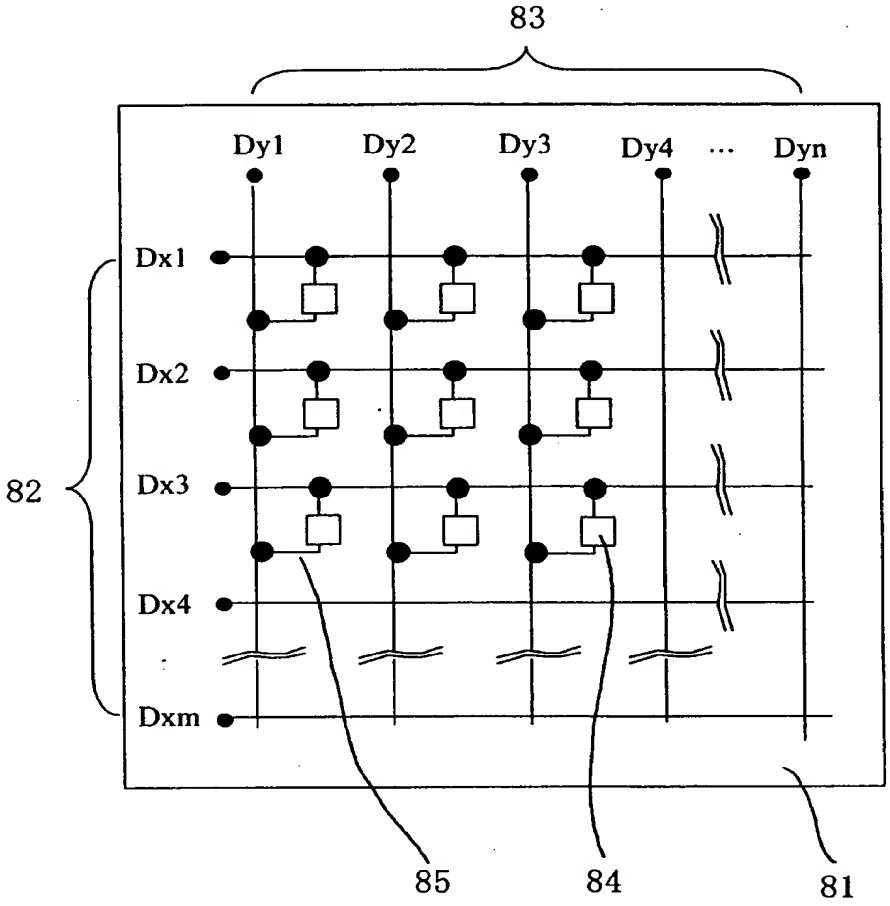
【図６】　Fig. 6



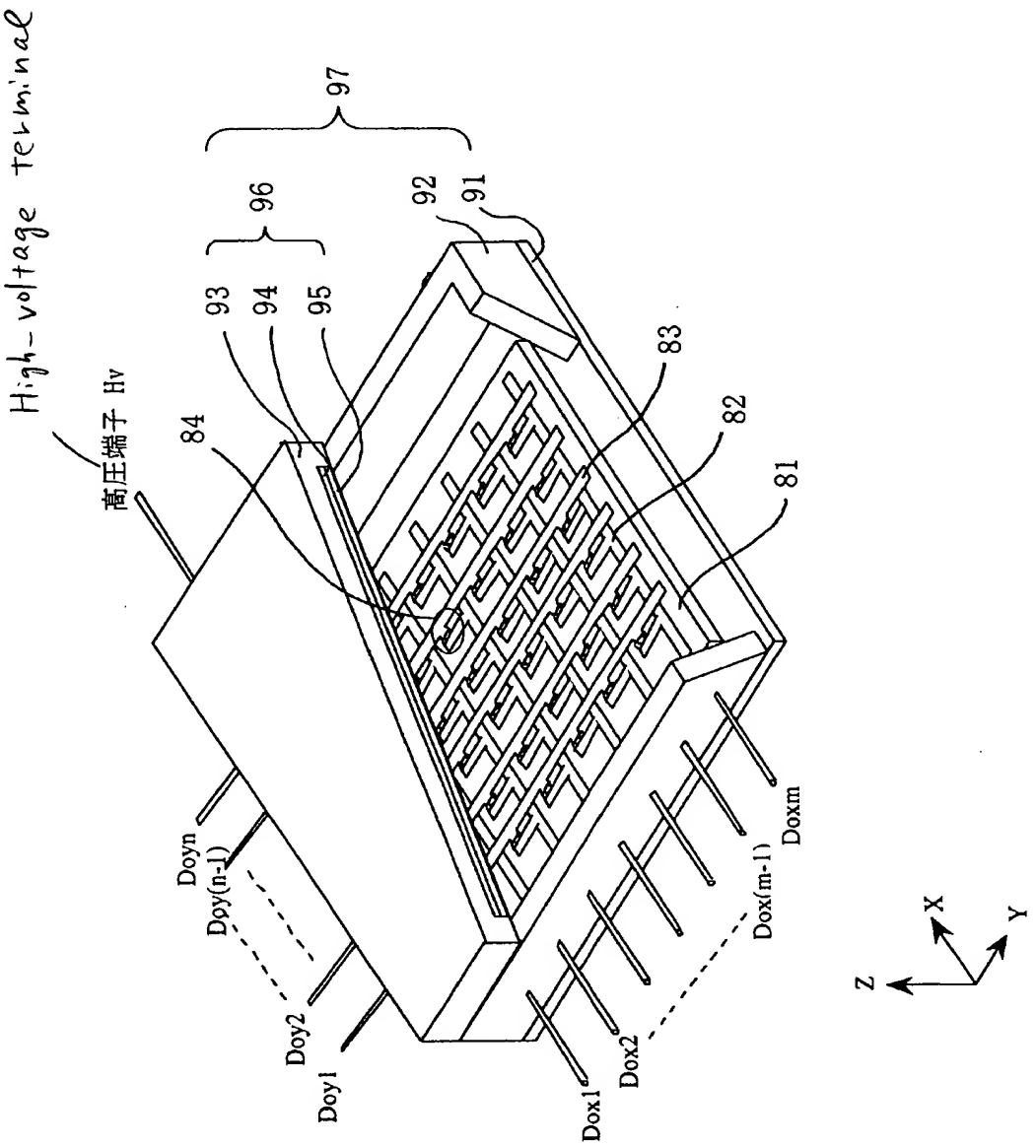
【図７】 Fig. 7


電子放出電流
Electron emission current
I_e
V_{th}
素子電圧　V_f
Device voltage

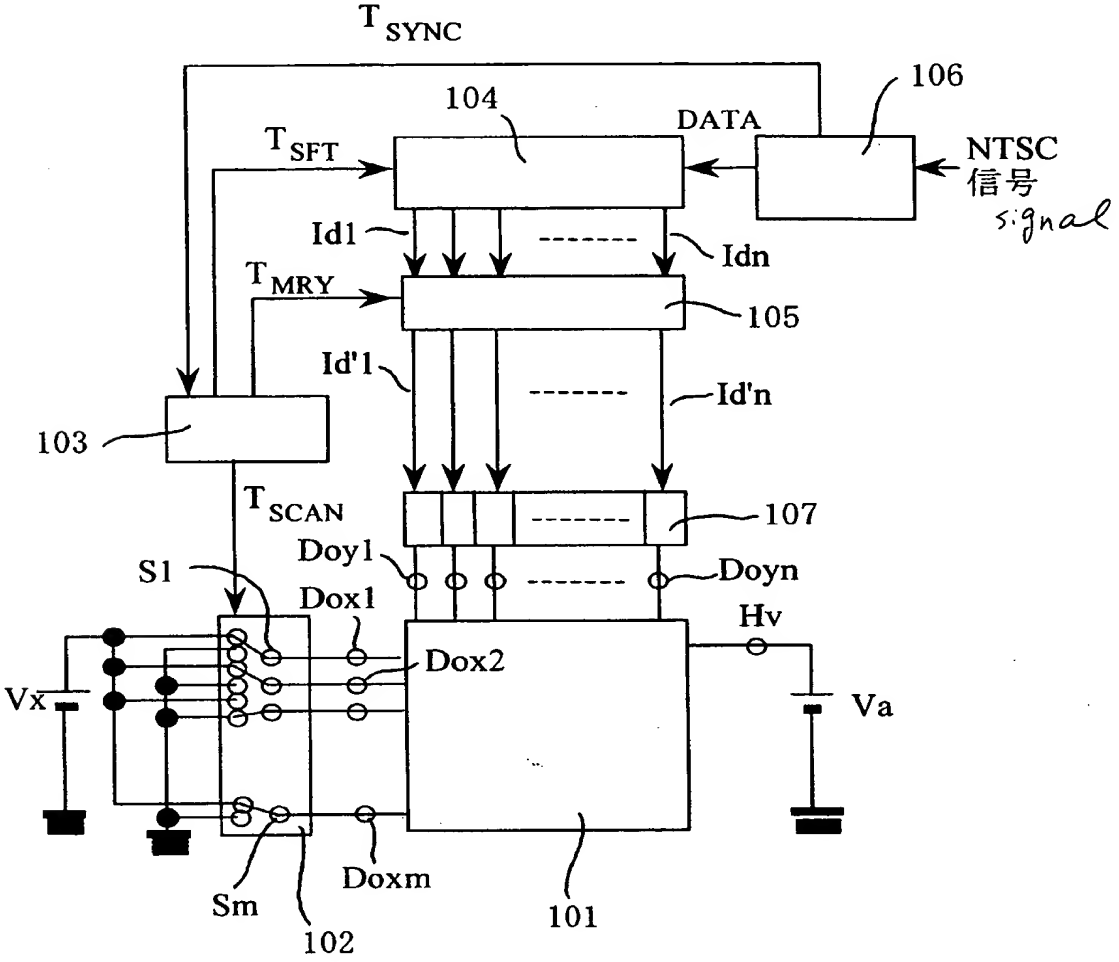
【図８】 Fig. 8



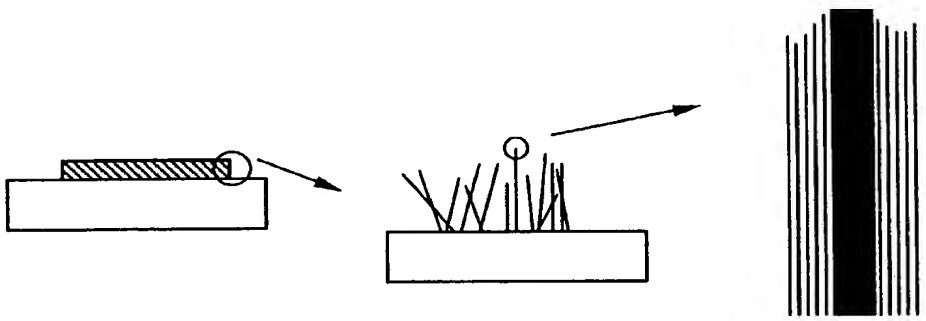
【図９】　Fig. 9


High-voltage terminal
高圧端子 Hv
97
96
92
91
93
94
95
84
83
82
81
Doyn
Doy(n-1)
Doy2
Doy1
Dox1
Dox2
Dox(m-1)
Doxm
X
Y
Z

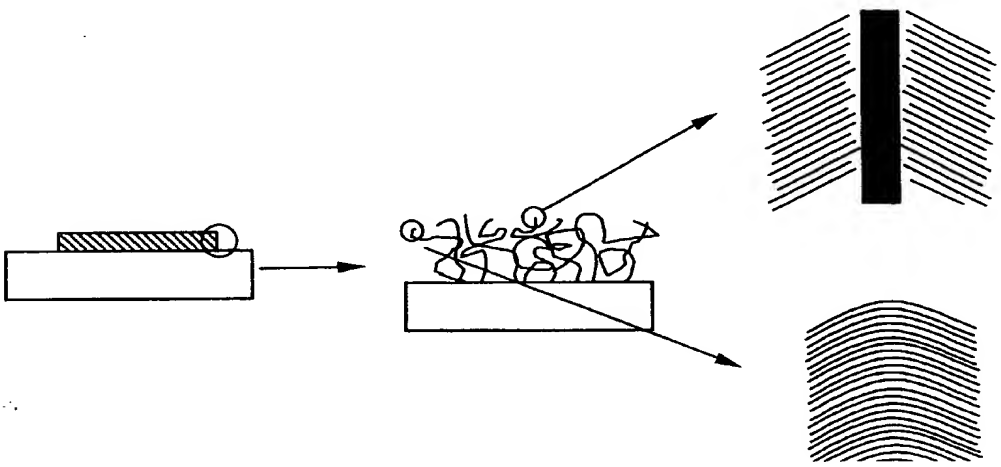
【図１０】 Fig. 10


T SYNC
104
106
DATA
T SFT
NTSC
信号
signal
Id1
Idn
T MRY
105
Id'1
Id'n
103
T SCAN
107
Doy1
Doyn
S1
Dox1
Hv
Dox2
Vx
Va
Sm
Doxm
102
101

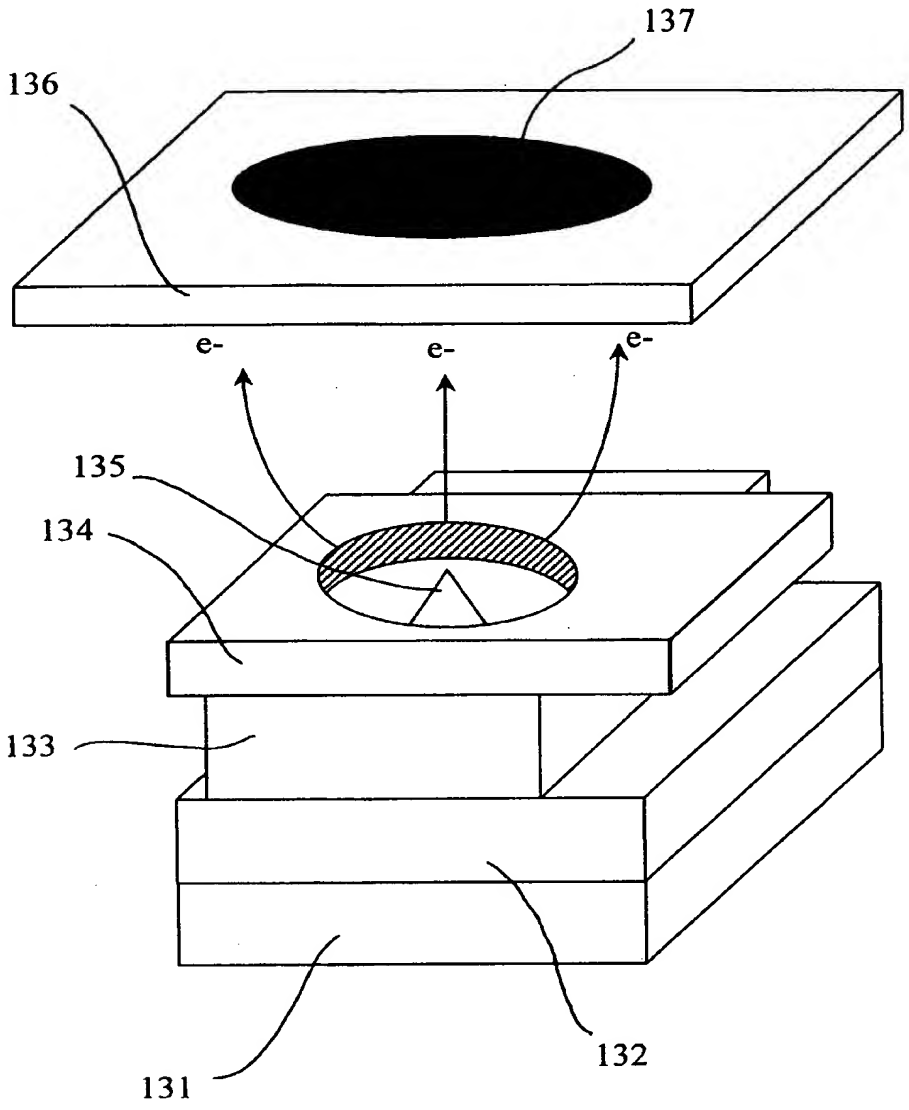
【図１１】 Fig. 11



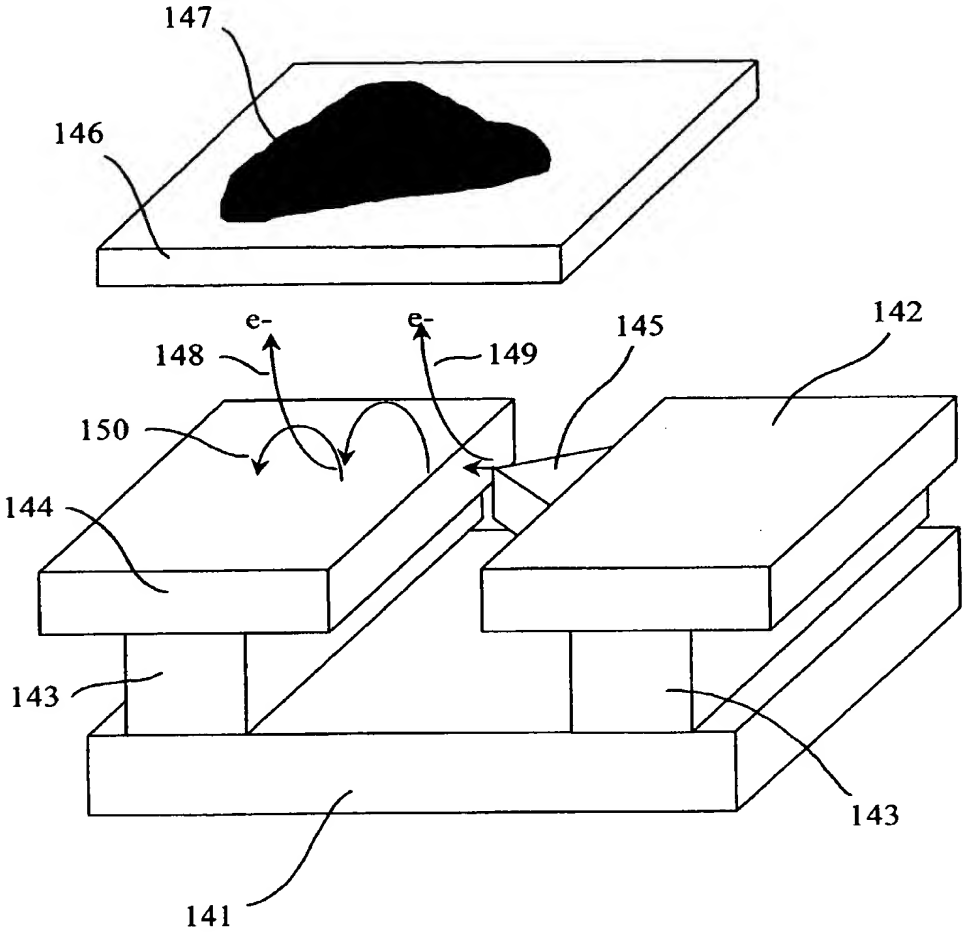
【図１２】　Fig. 12



【図１３】　Fig. 13



【図１４】　Fig. 14



[Name of the Document] Abstract

[Abstract]

[Problem(s)] Provided are electron-emitting devices, electron sources, and image-forming apparatus improved in electron emission efficiency and in convergence of trajectories of emitted electrons.

[Means for Solving the Problem(s)] The second conductive layer 6 on which no growth of fibrous carbon occurs through the catalyst particles is comprised so as to cover the region except for the side face of the conductive layer 5 on which growth of fibrous carbon occurs through the catalyst particles on the extraction electrode 2 side. As a result, only the side wall of the conductive layer 5 on which growth of fibrous carbon occurs on the extraction electrode 2 side is exposed, and thus the fibrous carbons 4 grow through the catalyst particles only on the side wall on the extraction electrode 2 side in the subsequent step of growth of fibrous carbons.

[Elected Drawing] Fig. 1

2000-265821

Applicant's Information

Identification No. [000001007]

1. Date of Change: August 30, 1990

(Reason for Change) New Registration

Address: 30-2, 3-chome, Shimomaruko, Ohta-ku, Tokyo

Name: CANON KABUSHIKI KAISHA

Certificate No. 2001-3083569